International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:7, 2012

Numerical Simulation for the Formability Prediction of the Laser Welded Blanks (TWB)

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Abstract**—**Tailor-welded Blanks (TWBs) are tailor made for different complex component designs by welding multiple metal sheets with different thicknesses, shapes, coatings or strengths prior to forming. In this study the Hemispherical Die Stretching (HDS) test (out-of-plane stretching) of TWBs were simulated via ABAQUS/Explicit to obtain the Forming Limit Diagrams (FLDs) of Stainless steel (AISI 304) laser welded blanks with different thicknesses. Two criteria were used to detect the start of necking to determine the FLD for TWBs and parent sheet metals. These two criteria are the second derivatives of the major and thickness strains that are given from the strain history of simulation. In the other word, in these criteria necking starts when the second derivative of thickness or major strain reaches its maximum. With having the time of onset necking, one can measure the major and minor strains at the critical area and determine the forming limit curve.

Keywords**—**TWB, Forming Limit Diagram, Necking criteria, ABAQUS/Explicit

I. INTRODUCTION

TAILOR-WELDED Blanks (TWBs) are tailor made for different complex component designs by welding multiple metal sheets with different thicknesses, shapes, coatings or strengths prior to forming [1]. Then the prepared blanks are formed to the desired shapes by appropriate forming method. For example in automotive industries, the final blank is stamped to the desired shape for the car body panel. In this technique, one can use the stronger or thicker sheets where needed and in this way a local stiffness is obtained which leads to product weight reduction without loss of stiffness and safety. The TWB technique has benefits for the producers, consumers and the environment due to weight reduction that causes less material and fuel consumption. Forming behavior is the most important factors in applying TWB in the automotive industries, although the cost should be studied, too. The Forming Limit Diagram (FLD) has been accepted for the formability prediction of sheet metals and could be used for TWBs. A forming limit diagram, also known as a forming limit curve, is used in sheet metal forming for predicting forming behavior of sheet metal [2,3]. The concept of the FLD was developed by Keeler et al [4] and Goodwin [5] and then become industrialized concept, could be achieved theoretically and experimentally.

To find the FLD, the sheet metal is subjected to various combinations of principal stresses (σ_1 and σ_2) to create different combination of principal strains (ε_1 and ε_2). For this purpose, usually the sheet metal specimens are stretched with constant length and variable widths via a hemispherical punch (out-of-plane stretching) or flat punch (in-plane stretching), or stretched with single geometry specimens with different lubricants. As the experimental method is both expensive and time consuming, in this paper a numerical simulation method is introduced by which precise, rapid and less expensive FLDs are produced only with applying the mechanical properties that resulted from uniaxial tensile test.

In recent years, many researches have attempted to develop precise and reliable models to find FLCs of base metals and several necking criteria have been proposed to predict the onset of localized necking [6,7]. For the predicting forming limit of Tailor Welded Blanks, Naik et al introduced some necking criteria, namely the effective strain rate based criterion (ESRC – RC1), major strain rate based criterion (MSRC – RC2), thickness strain rate based criterion (TSRC – RC3), and thickness gradient based criterion (TGNC – RC4) [8]. For the present work these criteria were evaluated and among them two criteria were preferred to develop an accurate model to find FLCs of TWBs.

II. METHODOLOGY

The Hemispherical Die Stretching (HDS) test via ABAQUS/Explicit FE code is simulated in 3D space to evaluate and analyze the formability of TWBs. Dry friction state was assumed and the friction coefficient between the blank and the punch was assumed to be μ=0.1. The die modeled as rigid with 100mm diameter of punch and 105.6mm the diameter of matrix.

Holder and the punch were allowed to move in the Z direction along the axis of the punch and the matrix is fixed. The modeled die is shown in the Figure 1 and the blanks were modeled as deformable solid and meshed with the C3D8R elements.

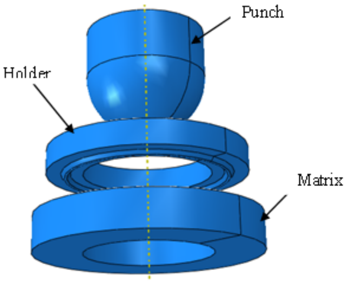

Fig. 1 Modeled HDS die

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As Panda et al have shown similar LDH results (less than 0.1 pct difference in the LDH) will be achieved both with and without the incorporation of soft zone and fusion zone (FZ) properties in the FE simulation[9], therefore, during the FE modeling, the soft zone and fusion hard zone can be omitted.

The stainless steel (AISI 304) was selected for the formability analysis based on the experimental results of the Chan et al [1]. The mechanical properties of this material are shown in the Table 1, and Figure 2 shows engineering stress-strain curves, but in the modeling the material true stress-strain data have been used. The density also considered as 7900 kg/m^3 and to define the elastic properties, Young's modulus is taken as 197 GPa and Poisson's ratio is taken as 0.29.

TABLE I
MECHANICAL PROPERTIES OF SHEET METALS

Thickness(mm)	1	1.2
Yield Strength(Mpa)	355	372
Tensile Strength(Mpa)	1112	1205
Necking Strain	0.37	0.39
Normal Anisotropy(r_m)	1	1
Strain Hardening Exponent, (n)	0.45	0.45

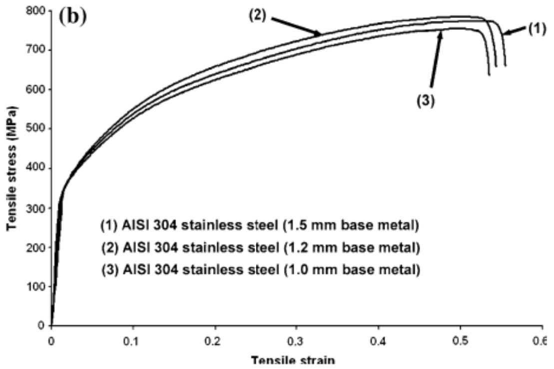

Fig. 2 Stress Strain Curves of Stainless Steel Base Metals [1]

III. NECKING CRITERIA

Selecting a suitable necking criterion is the essential problem that must be solved to find the limit strains. As mentioned earlier, two criteria were chosen to detect onset necking. These criteria that are based on the strain history of the simulation are the second derivative or acceleration of major strain and thickness strain. After the simulation, the strain history must be extracted and evaluated. Specimen of width 100 mm and length 200 mm of stainless steel AISI 304 having 1 mm thickness were used as an example to analyze this simulation process and to determine the onset of necking. After the simulation the strain history data were extracted as shown in the Figure 3 and fitted with Gaussian equations which showed good adaptivity with the strain history data. After the curve fitting and plotting first and second derivative of strain history, one can determine onset necking time and fracture time.

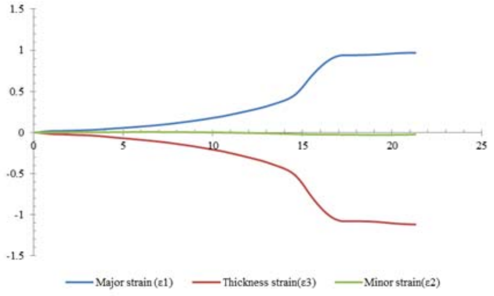

Fig. 3 Major, Minor and Thickness Strains

IV. SECOND DERIVATIVE OF MAJOR STRAIN

Figure 4 presents the contours of major strains elements of the stretched TWB. As it is shown in Figure 4, the major strain gradient near the weld line is more than other places, but this necking place depends essentially on the friction coefficient, lessening the friction coefficient will result in a closer necking, and necking also occur in the thinner blank. Here, the second derivative of major strain or major strain acceleration determines the onset of the necking.

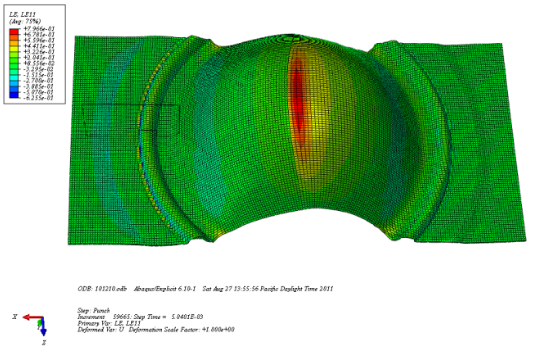

Fig. 4 Contours of Major Strain of a TWB (1mm/1.2mm, 100×200mm)

In Figures 5 and 6 the evolutions of major strain rate and major strain acceleration of a necked element are plotted, respectively. It can be seen that major strain acceleration in the 14.72 s, reaches its maximum, that means the onset necking, and major strain rate in the 15.50 s, reaches its maximum that means the fracture of specimen.

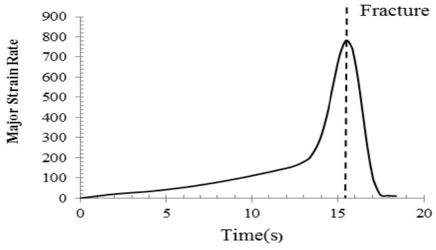

Fig. 5 First Derivative of Major Strain

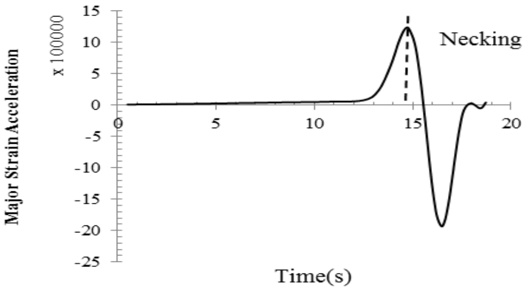

Fig. 6 Second Derivative of Major Strain

V. SECOND DERIVATIVE OF THICKNESS STRAIN

As shown in Figure 7 and in comparison with Figure 4, the thickness strain gradient and the major strain gradient take place in the same place. Comparing these figures with Figure 3, one can find that their changes are proportionate. The method of finding the onset necking time with this criterion is similar to the first criterion. But notwithstanding of these similarities these results are different together as shown in the Table 2. Figures 8 and 9 show first derivative and second derivative of thickness strain, respectively. Figures 8, 9 and Table 2 show that with second derivative of thickness strain criteria, the necking onset at 14.62 s and fracture occur at 15.52 s.

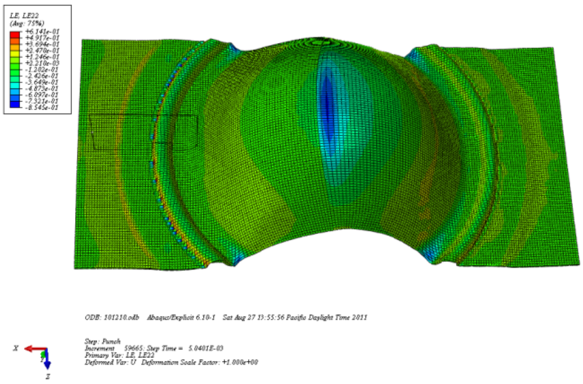

Fig. 7 Contours of Thickness Strain of a TWB (1mm/1.2mm, 100×200mm)

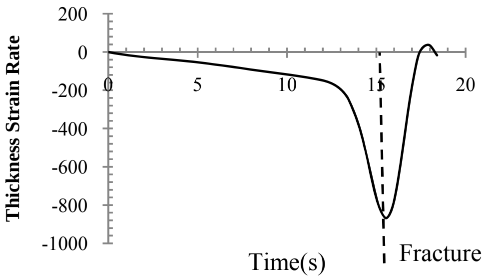

Fig. 8: First Derivative of Thickness Strain

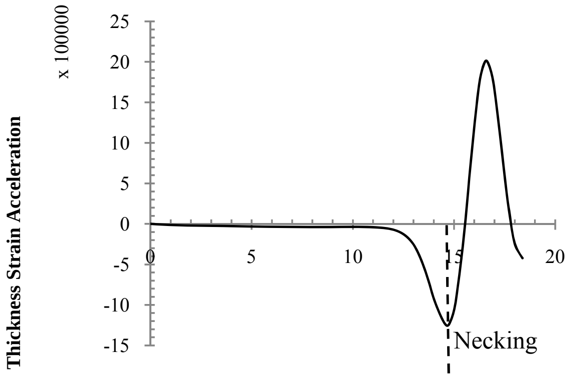

Fig. 9: Second Derivative of Thickness Strain

TABLE II
A COMPARISON BETWEEN THE RESULTS OF ANALYSIS VIA TWO CRITERIA

Necking Criterion	Major Strain Second Derivative($\ddot{}_1$)	Thickness Strain Second Derivative($\ddot{}_3$)
Necking Start Time(s)	14.72	14.62
Fracture Time(s)	15.50	15.52
Major Strain(ε_1)	0.48	0.47
Minor Strain(ε_2)	0.02	0.02

VI. LINEARITY OF THE STRAIN PATH

For research the linearity of the strain path until the forming limits, two points of 1.0/1.5 laser welded blanks have been considered, one from right hand side of the diagram (tension-tension side), and the other from the left hand side (tension-compression side). Figures 10 and 12 show the principal strain history of both points. The relation between the major strain (ε_1) and minor strain (ε_2) that named strain path is shown in Figures 11 and 13, too. The results indicate that the strain path of both points first is linear but not until the target point (necking) and then the strain path become non-linear and this may be due to the friction factor.

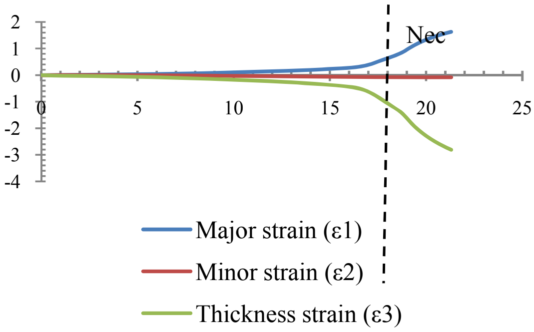

Fig. 10 Principal Strains of 80×200 mm specimen of TWB 1.5/1.0 mm

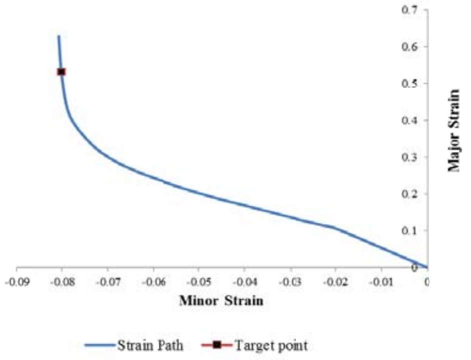

Fig. 11 Strain Path of Left Hand Side of the FLD

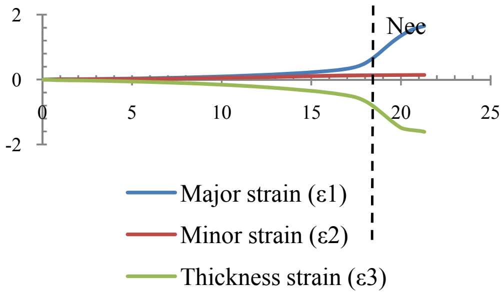

Fig. 12 Principal Strains of 140×200 mm Specimen of TWB 1.5/1.0 mm

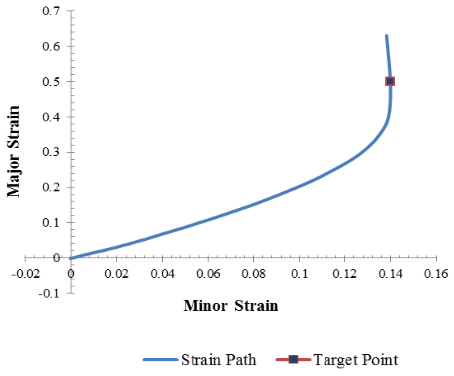

Fig. 13 Strain Path of Right Hand Side of the FLD

VII. RESULTS AND DISCUSSION

The forming limit diagrams of TWBs are predicted using two necking criteria, second temporal derivatives of major strain and thickness strain. Figures 14 to 18 show the analytical calculated FLCs of stainless steel (AISI 304) base metal and TWBs with both first criterion (second derivative of major strain) and second criterion (second derivative of thickness strain), in comparison with experimental results from Chan et al [1].

Majority of results show that the results of second criteria are closer to the experimental results. But the comparison between the Figure 4 and Figure 7 show that both criteria detect the same place as the necked zone.

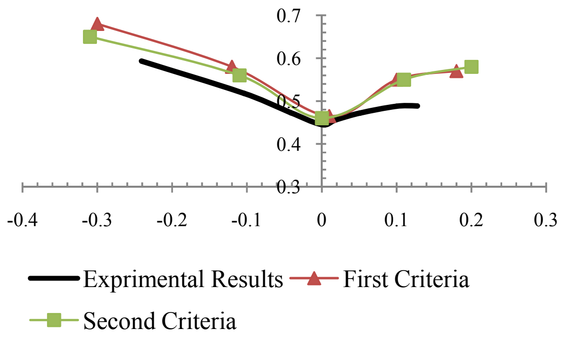

Fig. 14 FLCs of Base Metal 1.0 mm

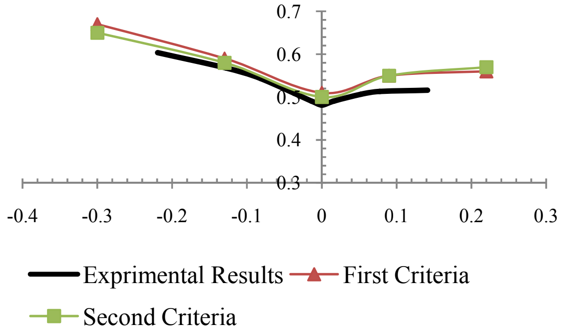

Fig. 15 FLCs of Base Metal 1.2 mm

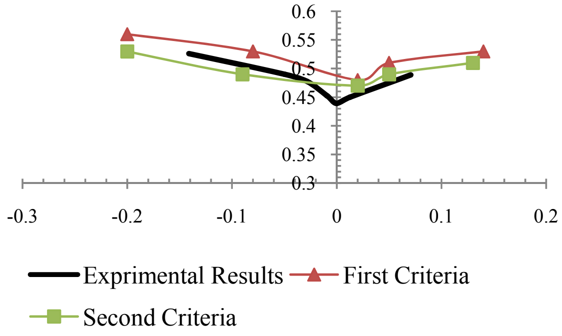

Fig. 16 FLCs of TWB 1.0/1.2 mm

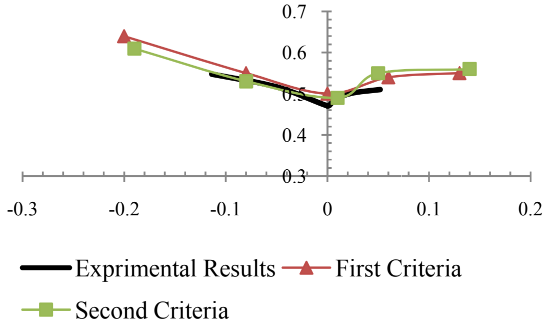

Fig. 17 FLCs of TWB 1.2/1.5 mm

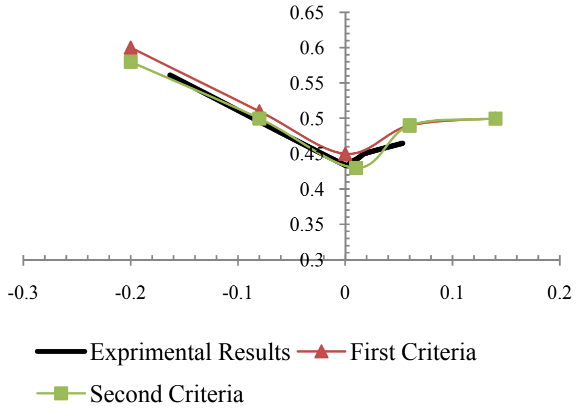

Fig. 18 FLCs of TWB 1.0/1.5 mm

VII. CONCLUSIONS

The main aim of the reported work was the presentation of two FE model to predicting the formability of TWBs with two necking criteria that may be more applied in the automotive industry that use TWB technology. Following conclusions can be drawn from the study.

- Both criteria show the same results for necking place and fracture time. As shown in the Figure 4, Figure 7 and Table. 2, both the second derivative of major strain and thickness strain with good accuracy are similar in prediction the necking zone and fracture time. Therefore, one can use both of them for predicting the necked zone and fracture time in the industrial applications.
- Second derivative of thickness strain present more reliable results. Figures 14 to 18 show that the forming limit results of second criteria (second derivative of thickness strain) are closer to the experimental results and then the second criteria showing better accuracy. Therefore, when one need to predict the forming limits is better to use the second derivative of thickness strain as the necking criteria for modeling and simulation the process.

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